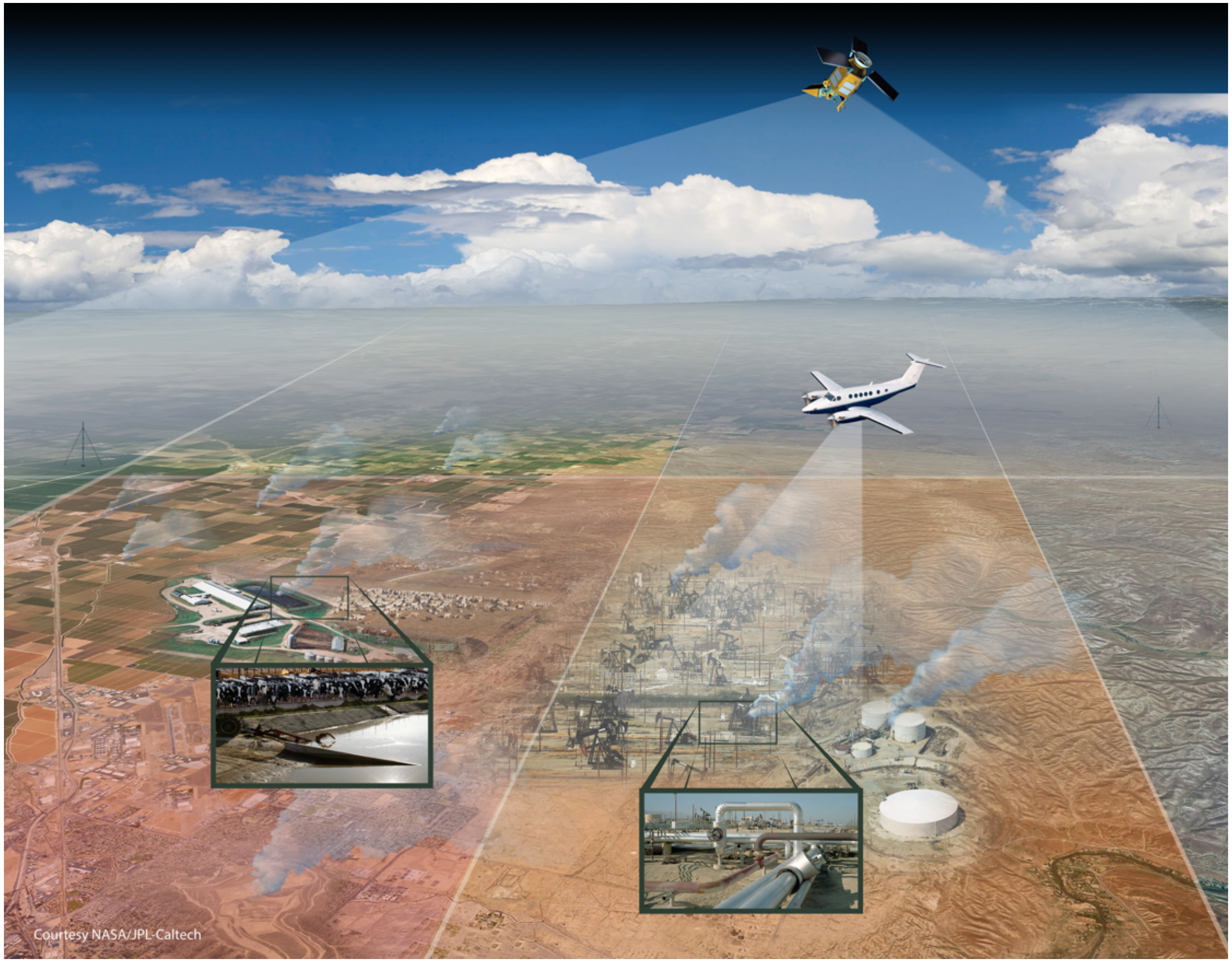
Tiered methane monitoring system for California



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Support from NASA's Carbon Monitoring System (CMS) and ACCESS programs

Overview

- Methane mitigation has emerged as a high priority for many sub-national entities ranging from state governments to cities and facility operators.

- Persistent observations of methane over large areas that are spatially and temporally complete and high resolution can provide actionable information.

- Prototype “tiered” methane monitoring system in California: combines atmospheric methane observations from multiple techniques and vantage points, geospatially resolved infrastructure data, machine learning, flux analysis, data fusion and data portal to assess and communicate methane emissions ranging from key regions to individual infrastructure elements.

- Observational tiers include satellite observations spanning the state of California, periodic statewide airborne remote sensing surveys of point sources, a regional network of tower-based in situ sensors and a geostationary satellite testbed overlooking the Los Angeles megacity.

- Goal: improve relevance of methane observations by developing and validating point source flux estimates, linking with multi-scale attribution data and flux estimates, and coordinating with California stakeholders to infuse products into decision-making.

California GHG Emission Reduction Goals

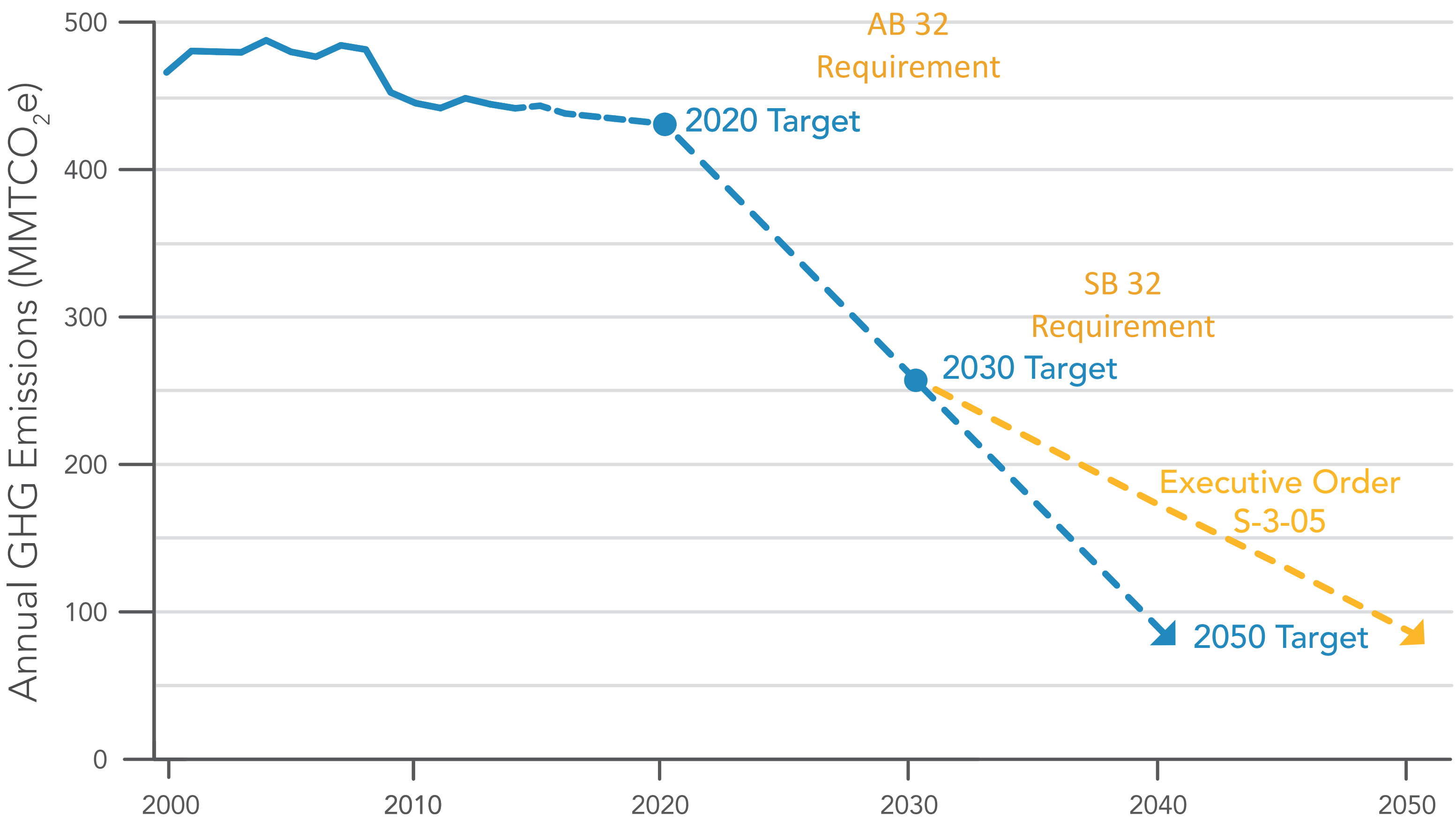
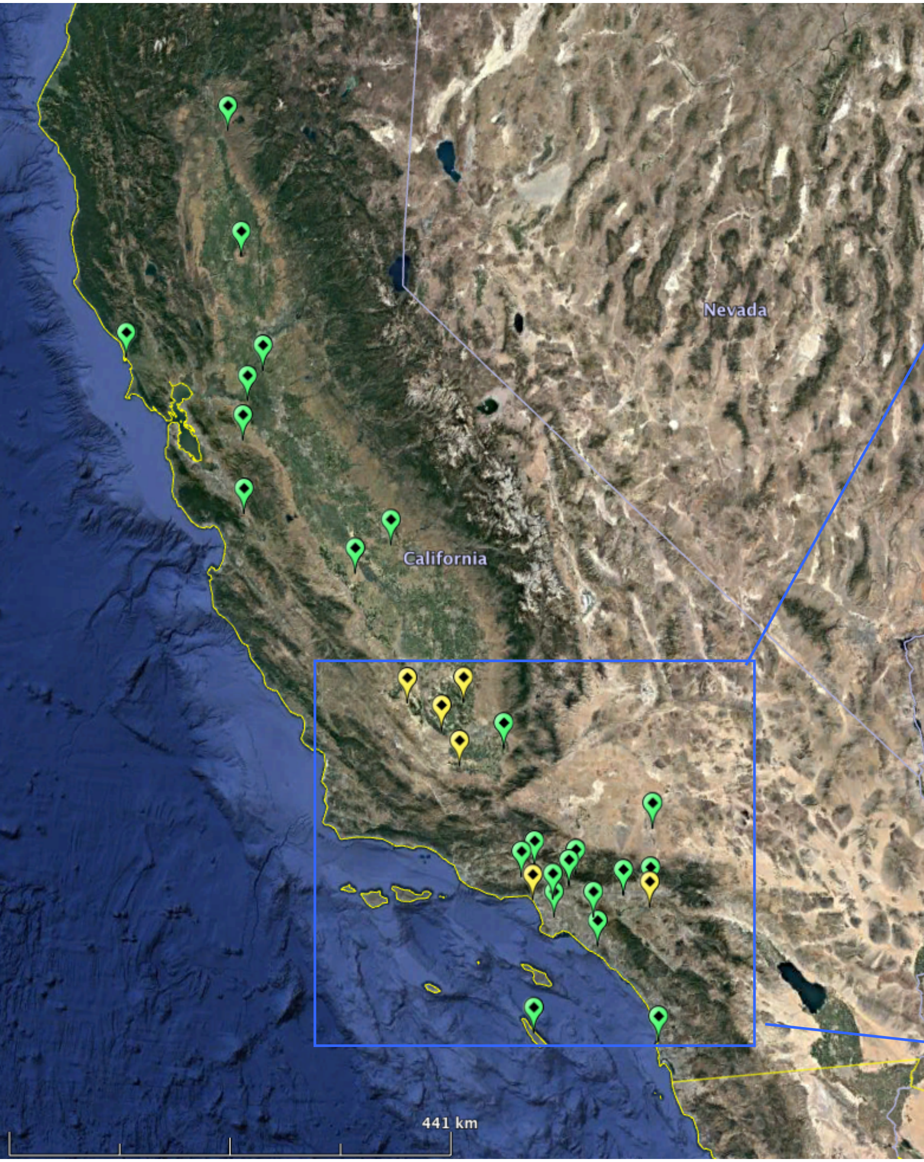
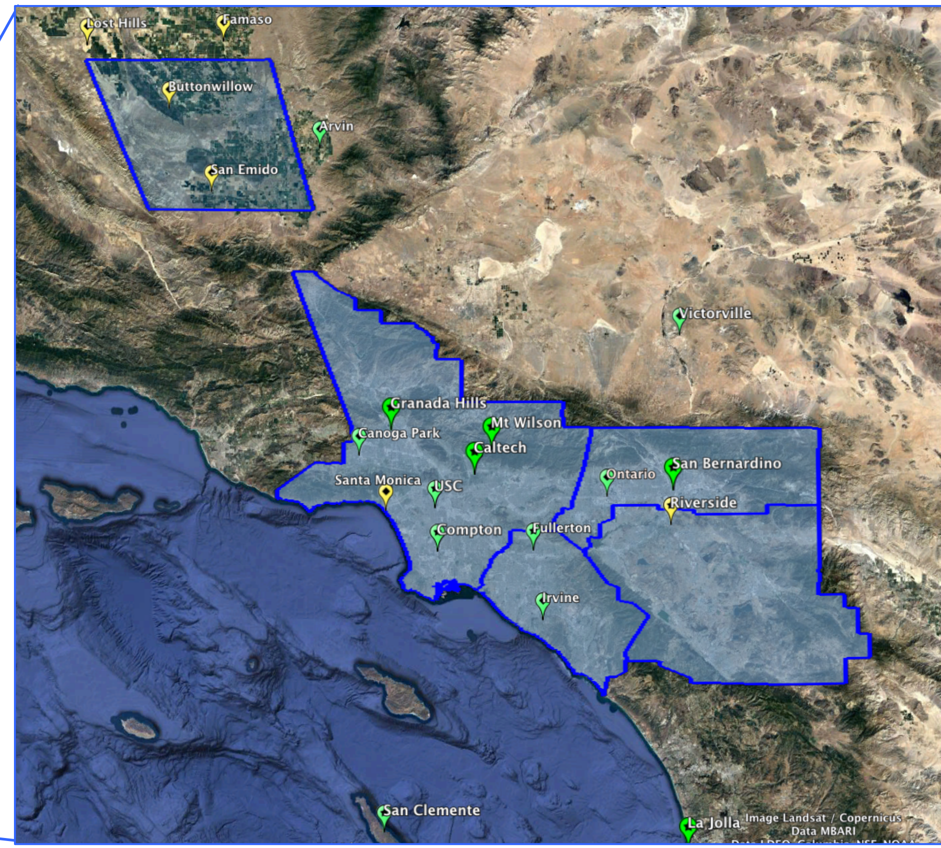


Figure courtesy CARB

California GHG Monitoring Networks

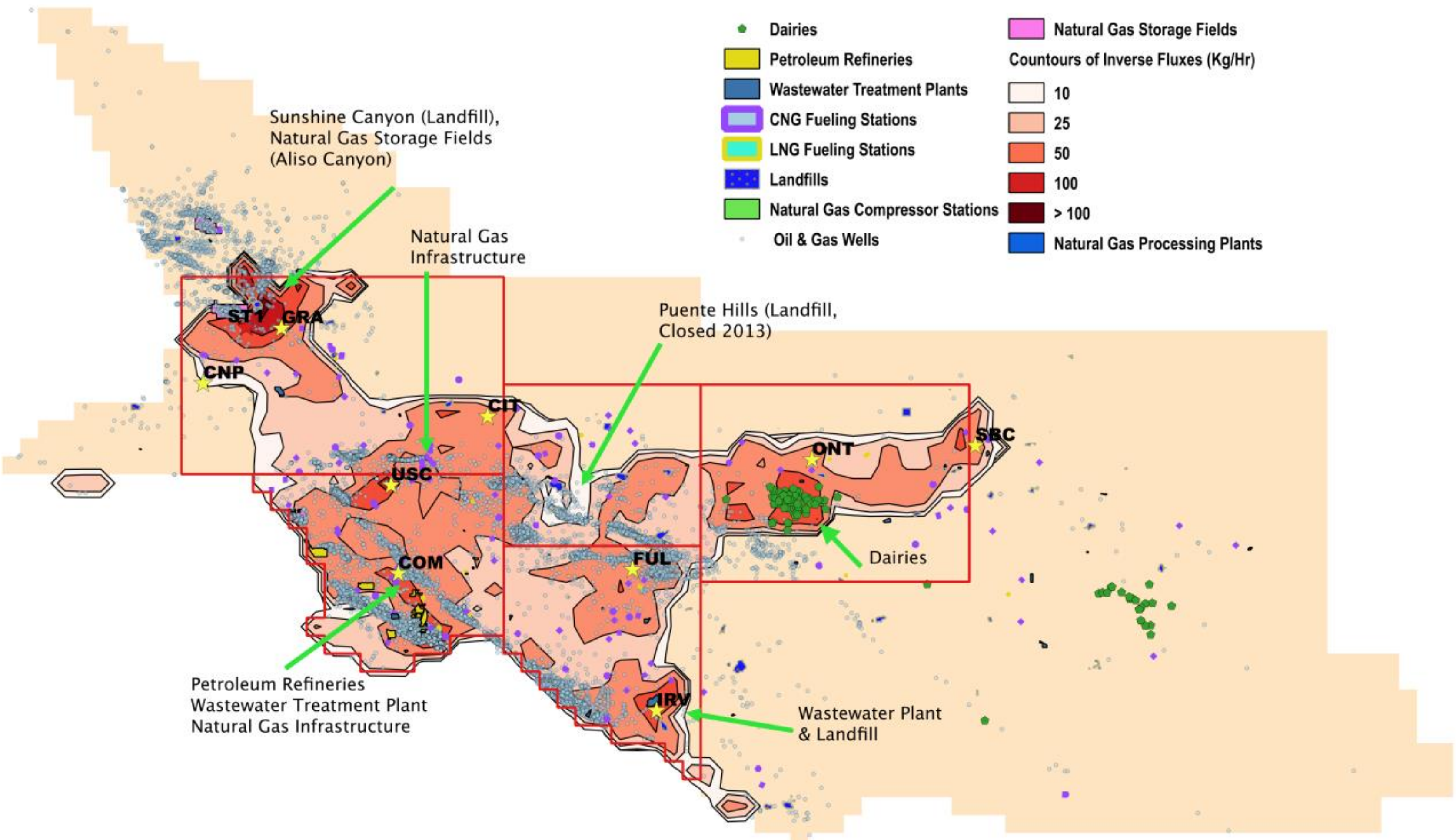


Federation of networks: CARB, BA-AQMD, JPL/Scripps/UCR, LBNL



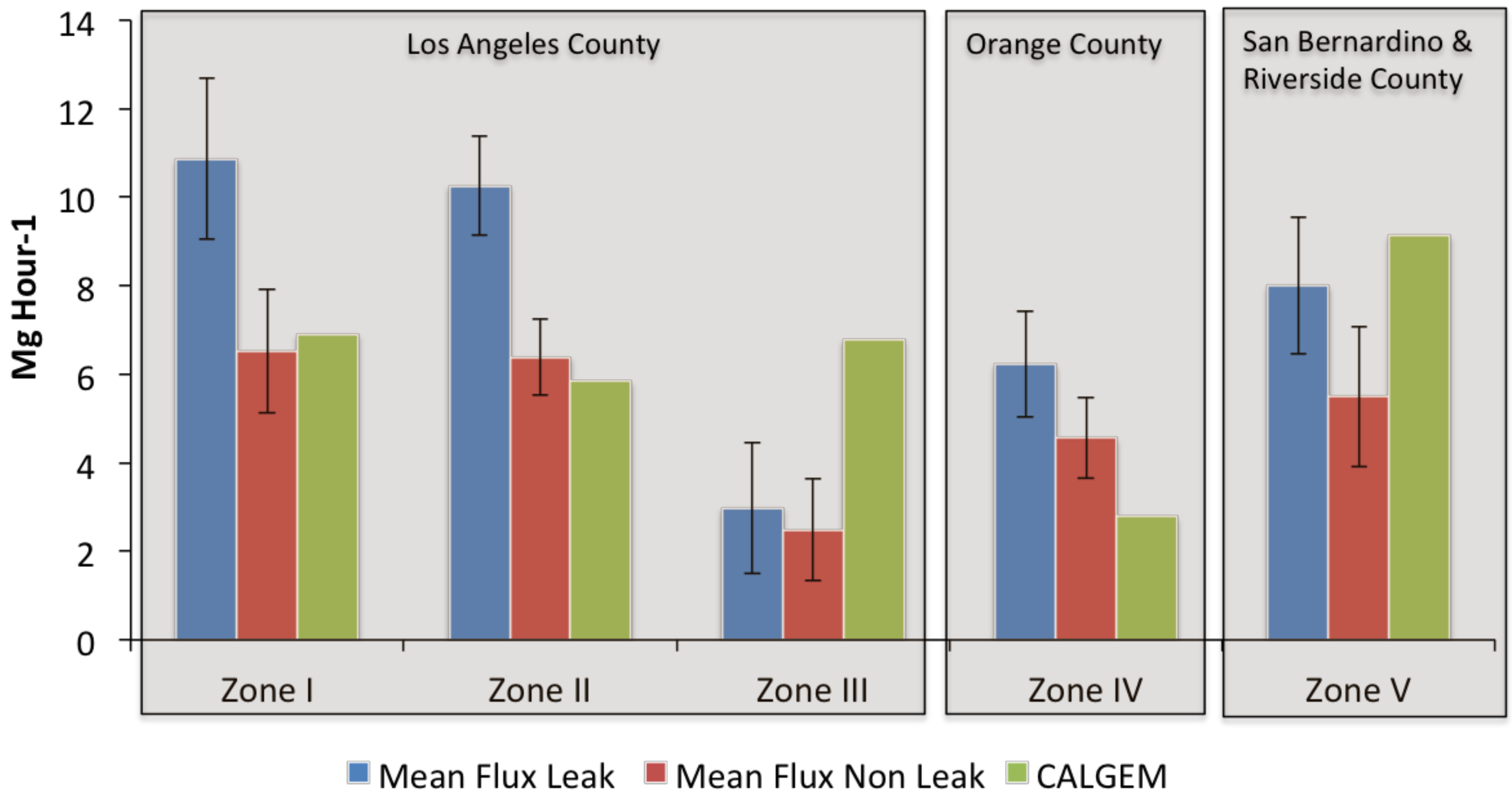
Near-continuous monitoring at 23 sites
Expand to at least 30 by 2020

Regional flux inversion: LA megacity



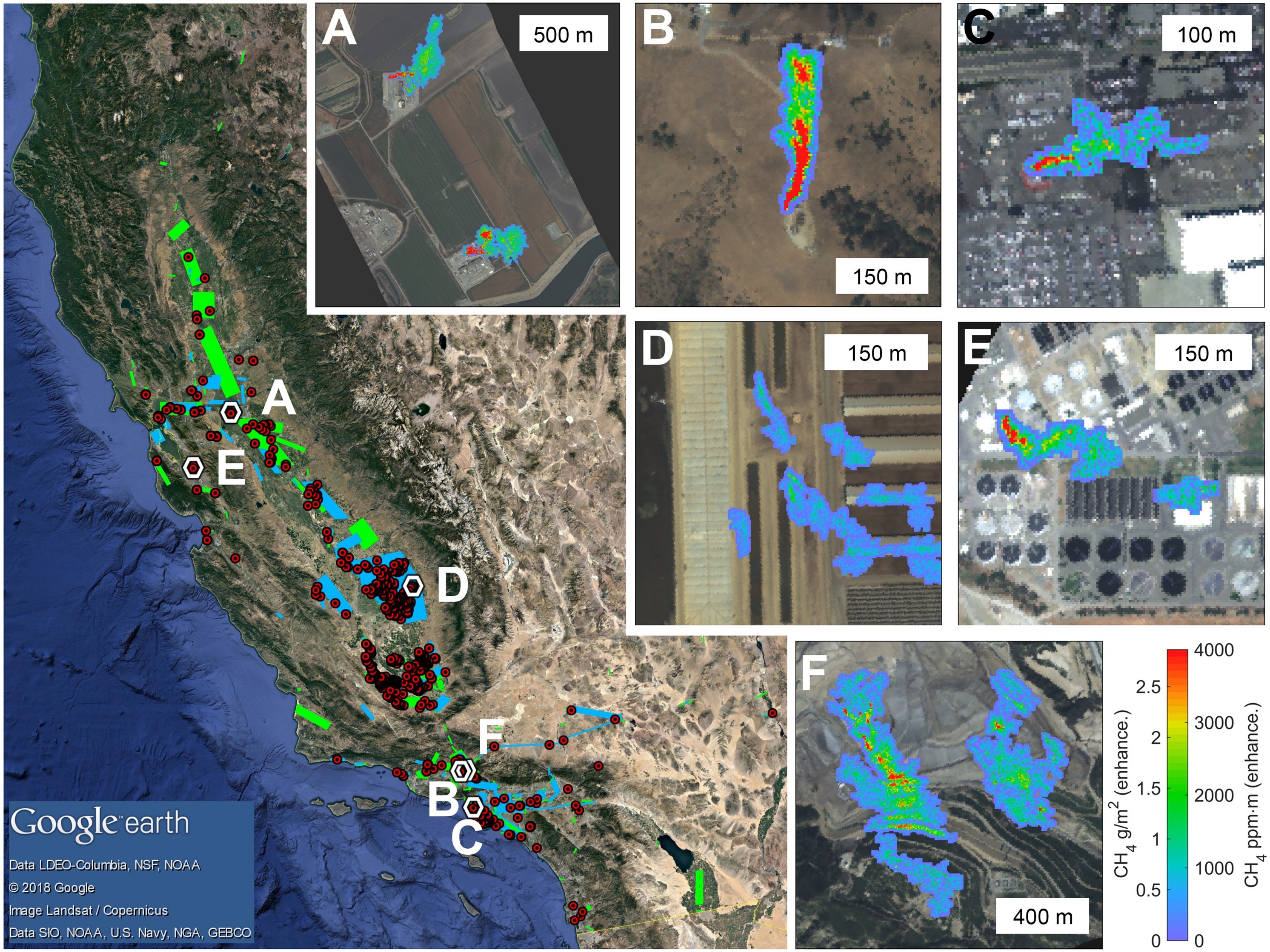
Yadav *et al.* 2019 in revision

Comparison of the inversion posterior fluxes (for both the Aliso Canyon leak period and the non-leak period) with 1-sigma uncertainties vs CALGEM for each of the five zones in the LA Megacity Domain (LAMD). The impact on the basin-wide flux from the Aliso Canyon gas leak is readily apparent. We attribute the large reduction in the posterior fluxes in Zone III to the shutdown of the Puente Hills landfill in 2013.



Yadav *et al.* 2019 in revision

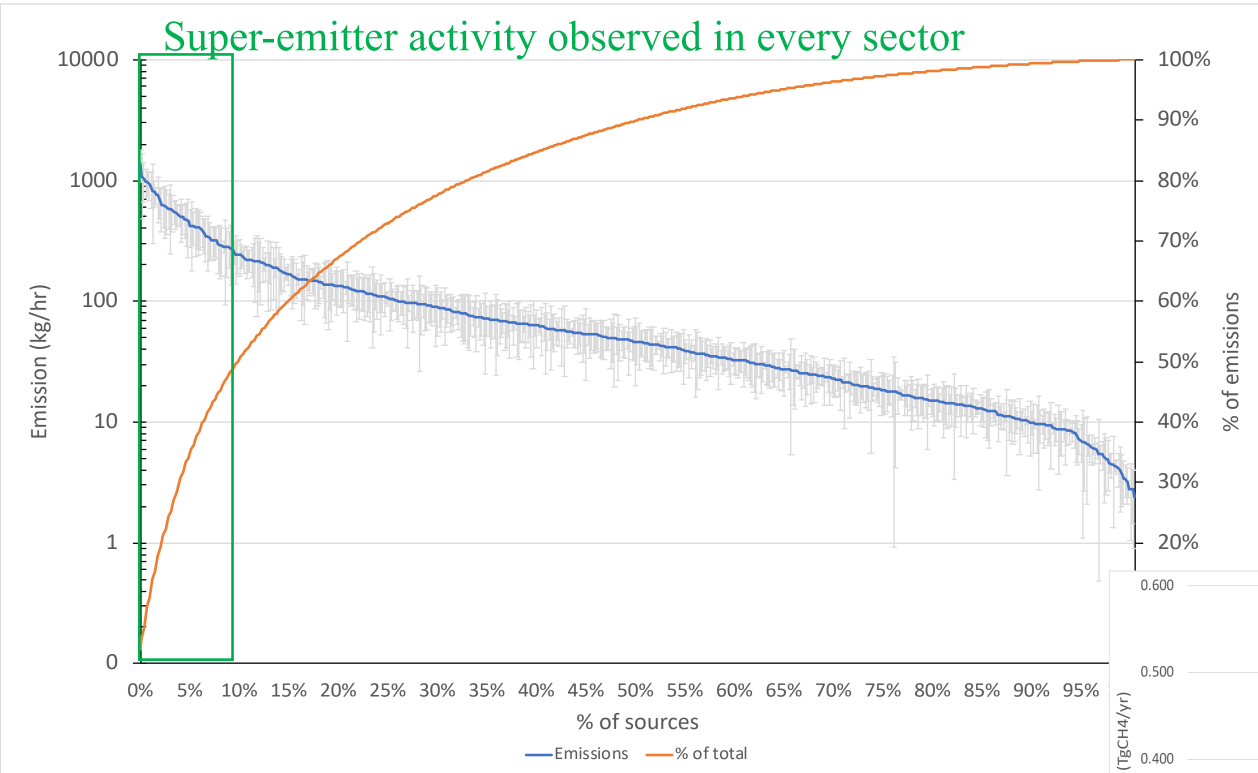
Statewide survey of point sources



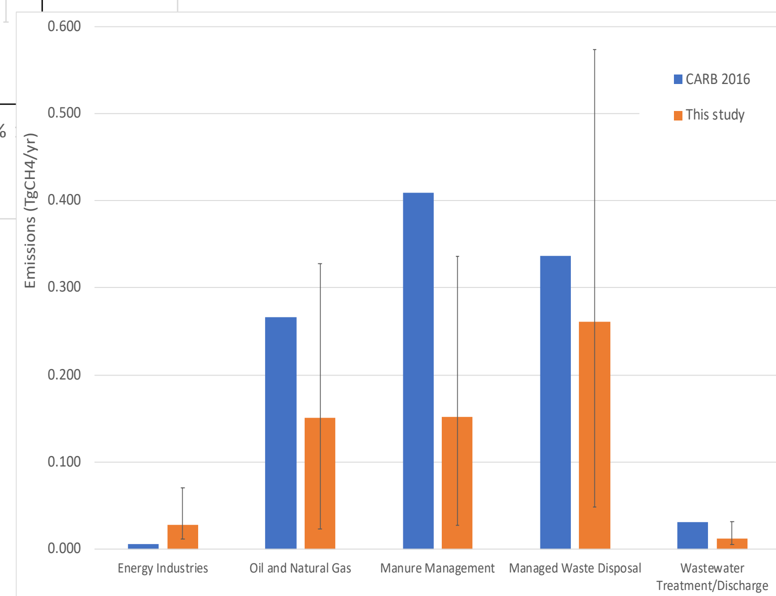
5 months of flights 2016-2018; repeat overflights of >272,000 facilities and components; >1300 plumes; 562 sources

Duren *et al.,* in revision

Anomalous super-emitters at 0.2% of infrastructure responsible 35-43% of California CH_4 inventory



50% of point source emissions from 10% of observed point sources

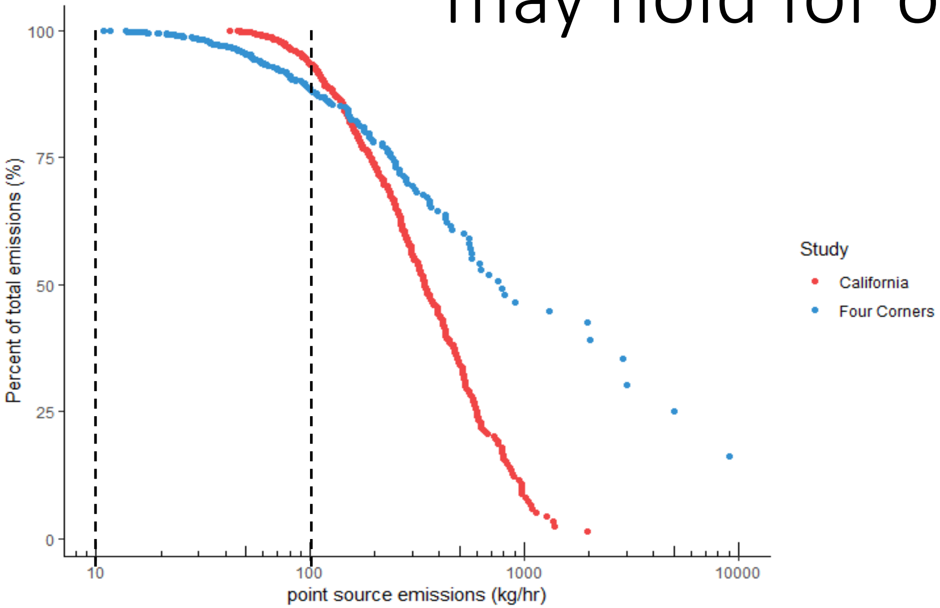


total methane point source emissions in California
0.607 (95% confidence 0.541-0.674) $TgCH_4\ yr^{-1}$

Duren *et al.*, in revision

California & 4 Corners results suggest relationship may hold for other key regions globally

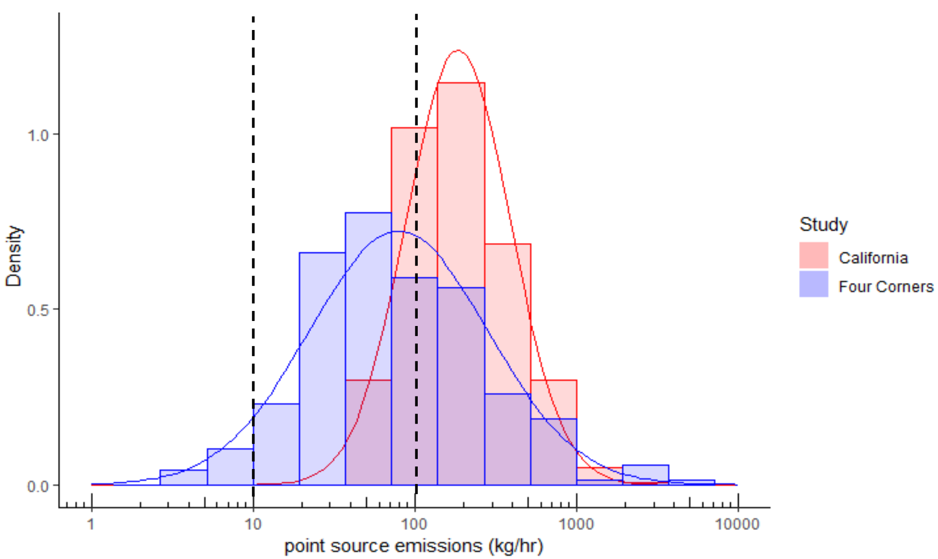
A



10 kg h^{-1}
from aircraft (3-6km)

100 kg h^{-1}
from LEO

B



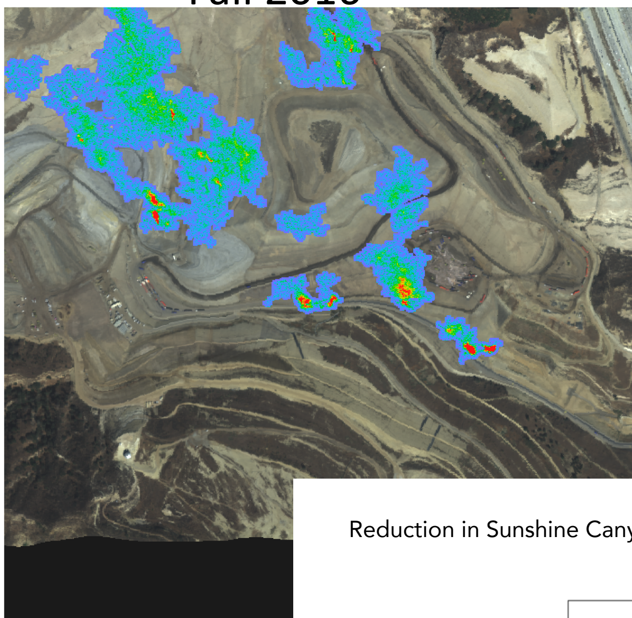
10X relaxation in detection limit still nets 90% of point sources and enables broader spatial coverage
→ **path to space**

100 kgCH_4 h^{-1} detection limit from LEO possible with AVIRIS-ng derivative instrument with 30m GSD, 5 m s^{-1} wind, moderate surface brightness, & nodding

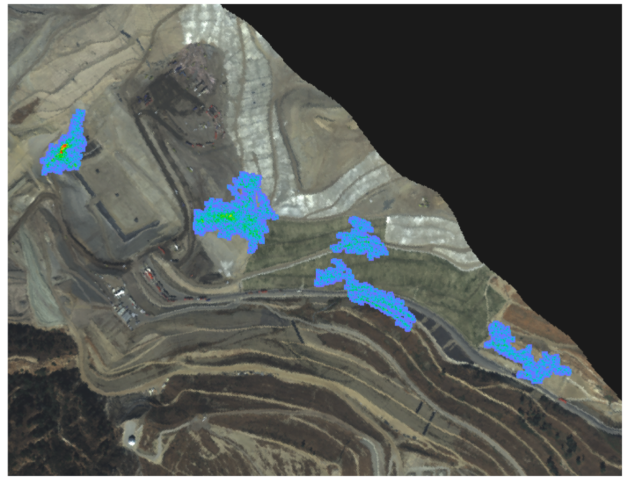
Duren *et al.*, in revision
Frankenberg *et al.*, *PNAS*, 2016

Tiered observing system in action: landfill emissions mitigation

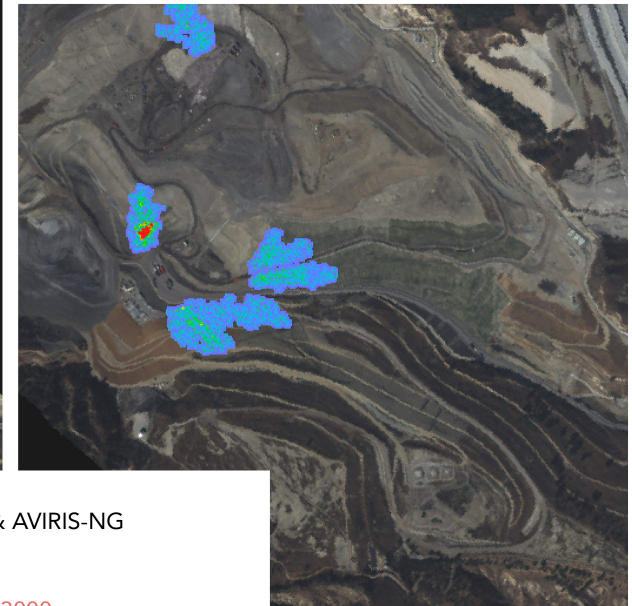
Fall 2016



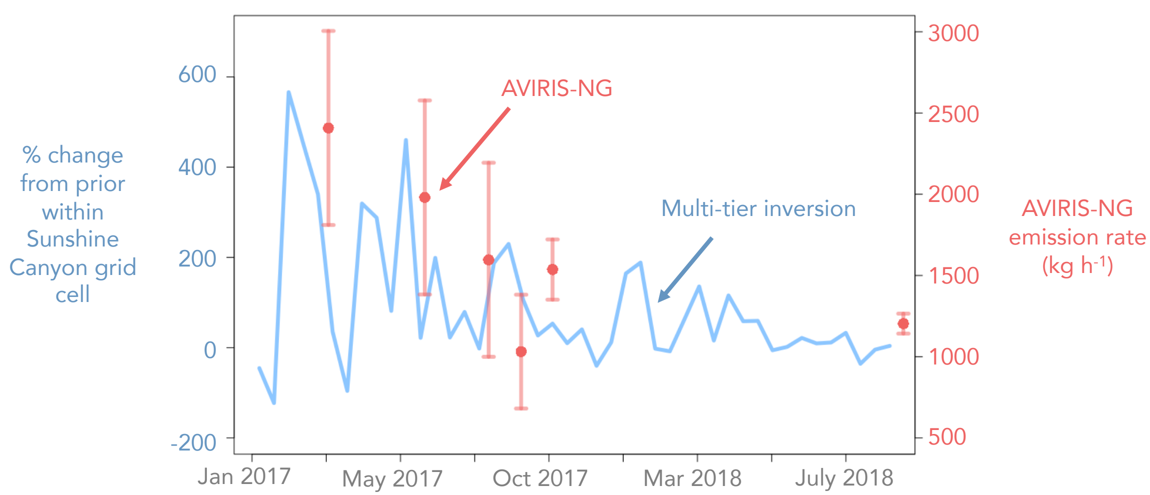
Fall 2017



Fall 2018



Reduction in Sunshine Canyon CH4 emissions seen by both tiered-observing inversion & AVIRIS-NG

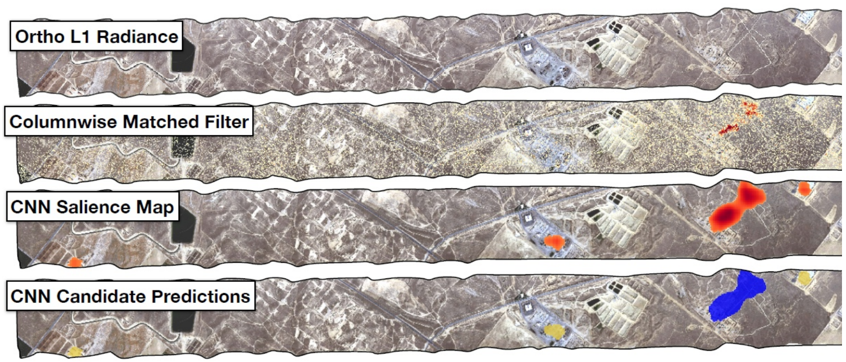


Cusworth *et al.*, in prep

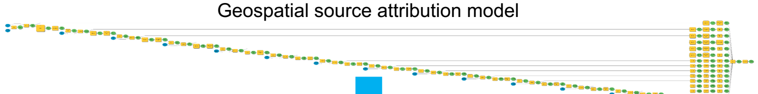
Observations in multi-tier: Megacities towers, CLARS, TROPOMI
Forward model / inversion: HRRR-STILT at 3km, Bayesian inversion using EPA inventory (assume factor 10 uncertainty)

New developments: automation & visualization

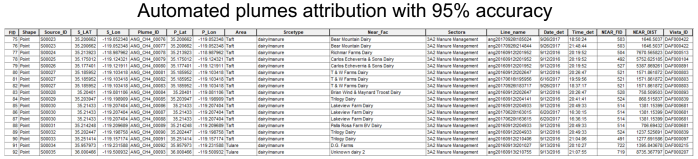
Machine learning (Feature detection & attribution)



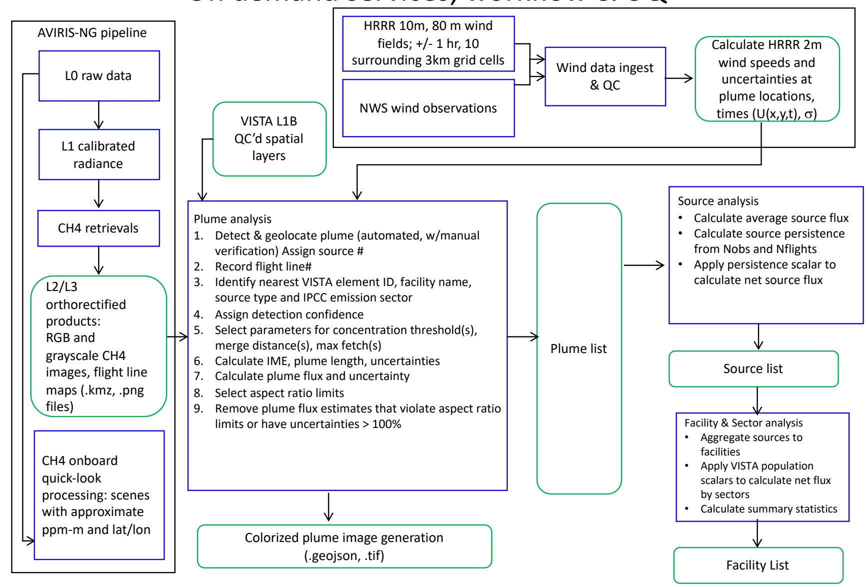
Geospatial source attribution model



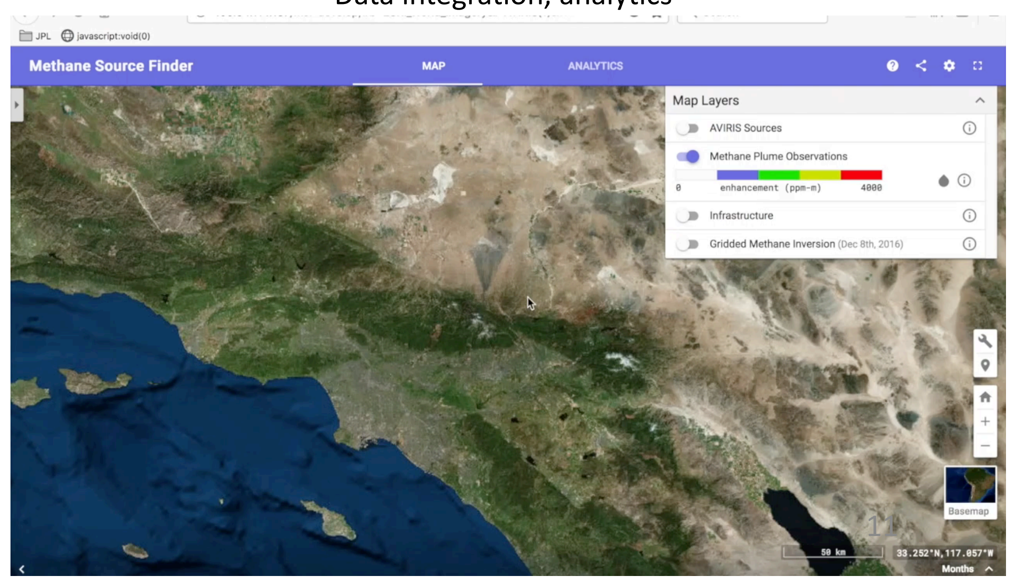
Automated plumes attribution with 95% accuracy



On demand services, workflow & UQ



Data integration, analytics



Summary

- Tiered observing systems offer the potential to combine persistent, spatially complete monitoring over large areas with point-source monitoring at facility scale

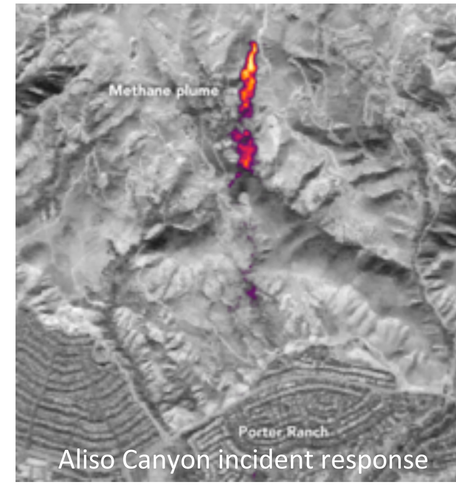
- Data sharing with facility operators can lead to voluntary mitigation if the data is able to guide mitigation at component levels

- Pilot efforts indicate potential to extend these methods globally through coordinated surface monitoring networks, periodic airborne remote-sensing surveys and/or satellite observations and with multi-scale analysis systems

- backup

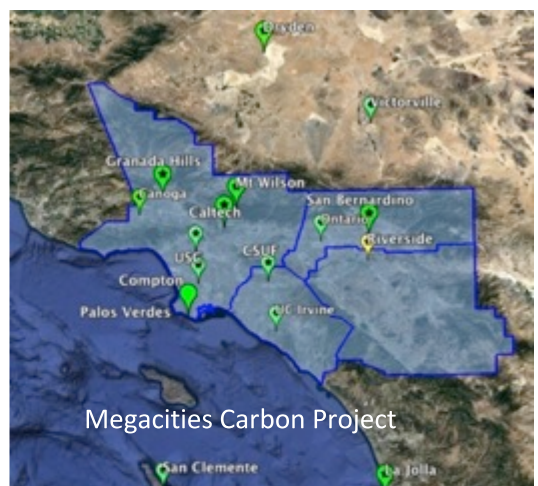
Methane Projects

- Megacities Carbon Project (NIST/NASA): persistent, multi-scale GHG monitoring for LA basin
- Aliso Canyon incident response (NASA): AVIRIS-C and HyTES, discovery of secondary plumes and oil well venting
- California Methane Survey (CARB/CEC/NASA): baseline statewide survey of point-sources (responsive to AB1496, SB888)
- ACCESS Methane Source Finder (NASA): automate workflow (point source detection, attribution and flux estimation pipeline) + analytics/portal
- CMS Prototype Methane Monitoring System for California (NASA): integrate aircraft, surface, & satellite inversions and infrastructure data (regional to point source scale)



Aliso Canyon incident response

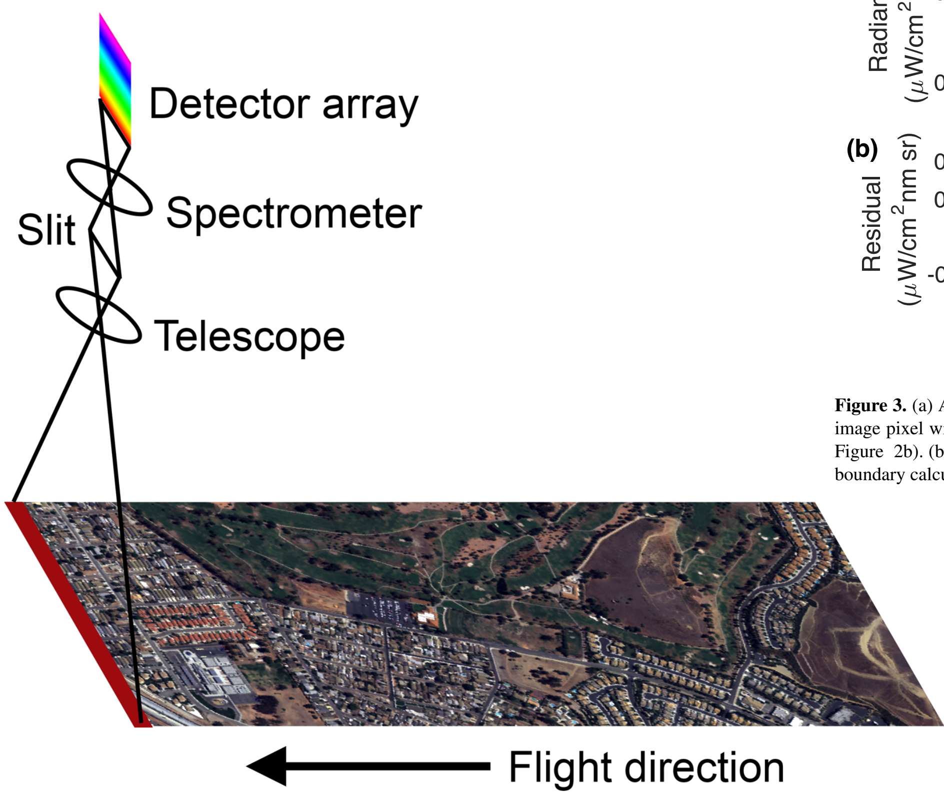
Cal Methane Survey



Megacities Carbon Project

Measuring CH_4 (and CO_2) with SWIR Imaging Spectroscopy

- Effort led by Andrew Thorpe and David R. Thompson (JPL)
- AVIRIS-NG has 5 nm spectral resolution (380-2510 nm) & typically 3 m spatial resolution, 1.8 km swath (at 3km altitude)



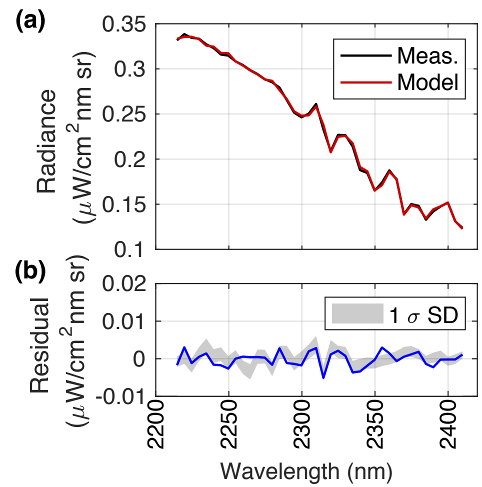


Figure 3. (a) AVIRIS-NG measured and modeled radiance for one image pixel within the CH_4 plume used for the CH_4 retrieval (see Figure 2b). (b) The residual is plotted with 1 σ standard deviation boundary calculated from residuals for the entire scene.

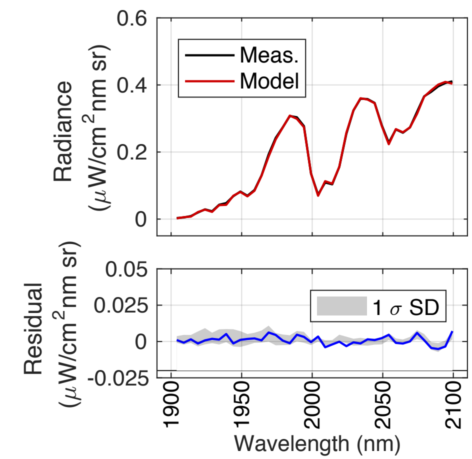


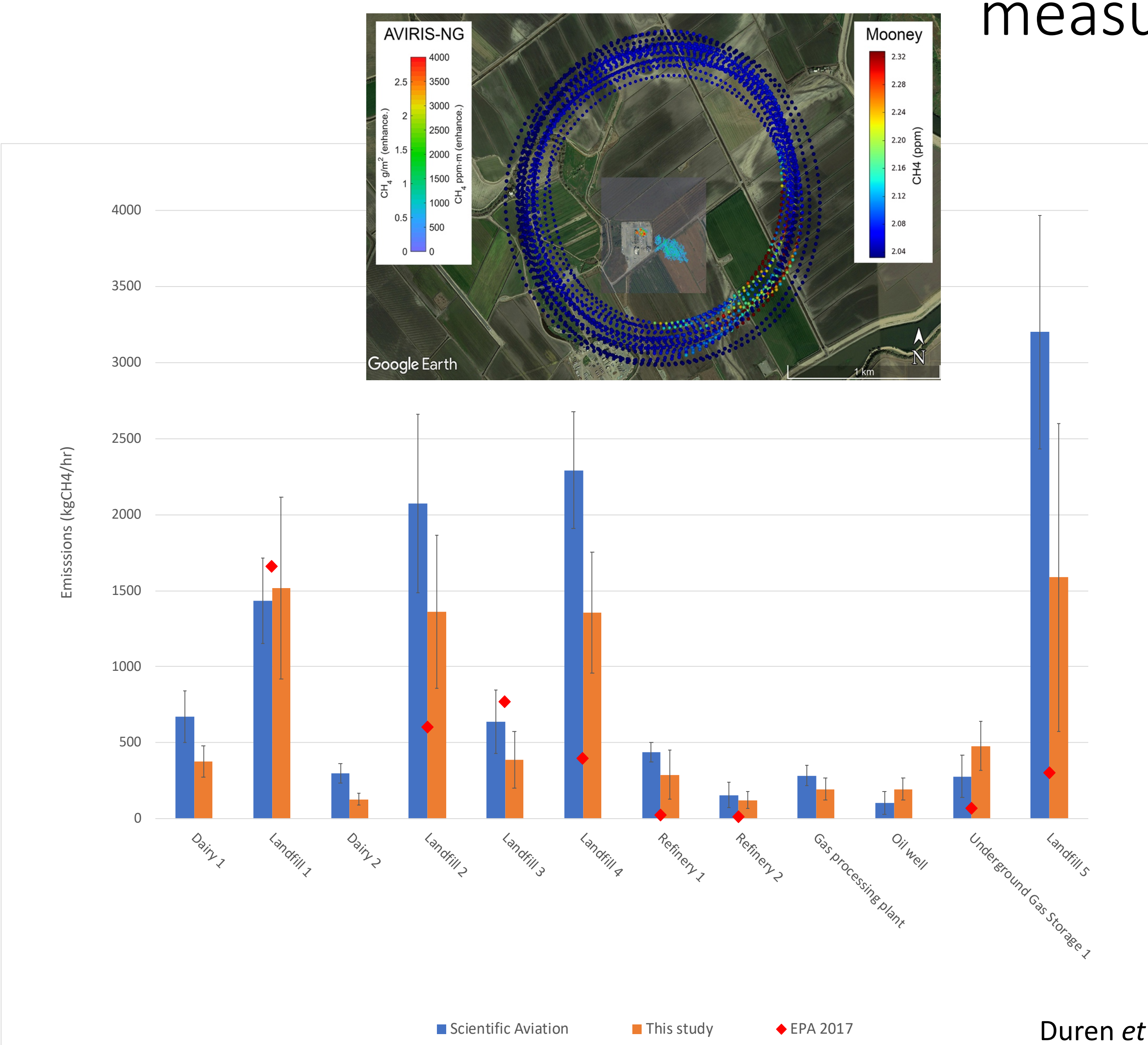
Figure 7. (a) AVIRIS-NG measured and modeled radiance for one image pixel within the CO_2 plume for the CO_2 retrieval (see Figure 6b). (b) The residual is plotted with 1 σ standard deviation boundary calculated from residuals for the entire scene.

Thorpe *et al., AMT*, 2017; Thompson *et al., GRL*, 2016

CH4 enhancement + wind speed → Emission flux

$$IME_{r_c} = k\sum_{i=0}^{n} \alpha(i)S(i) \qquad Q = \left(\overline{IME}/r\right)U_{10}$$

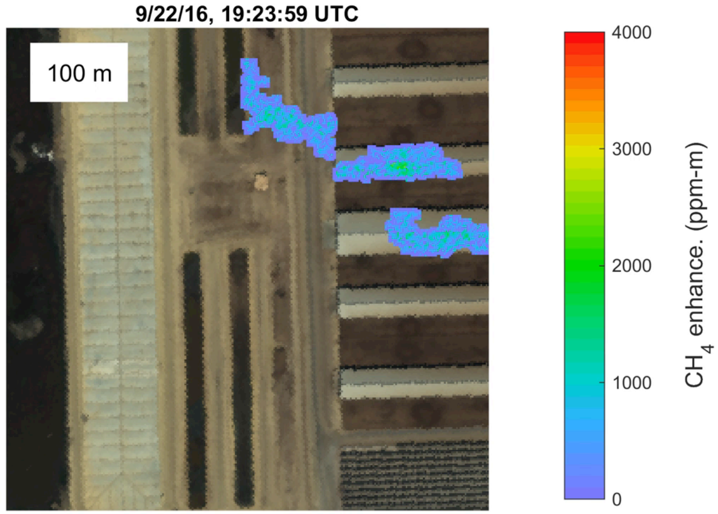
Validating emission estimates with in-situ measurements



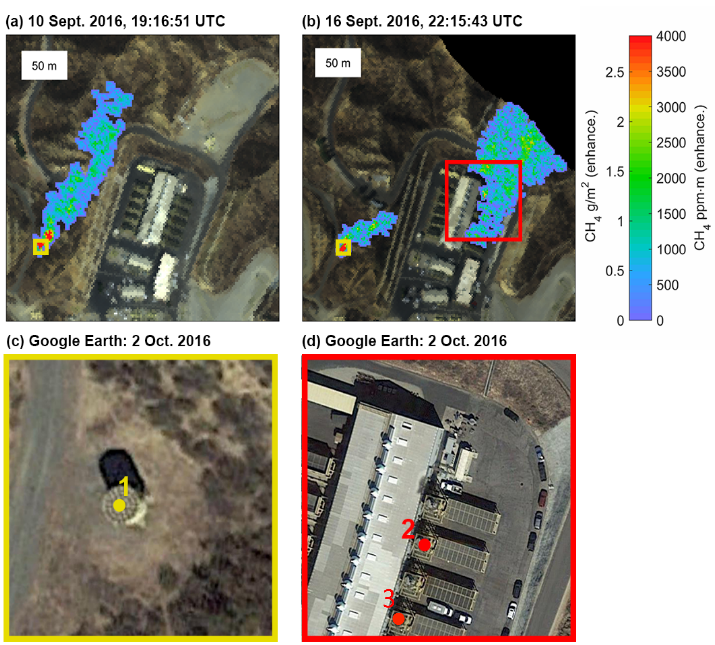
Duren *et al.*, submitted

Need frequent/persistent observations

Dairy

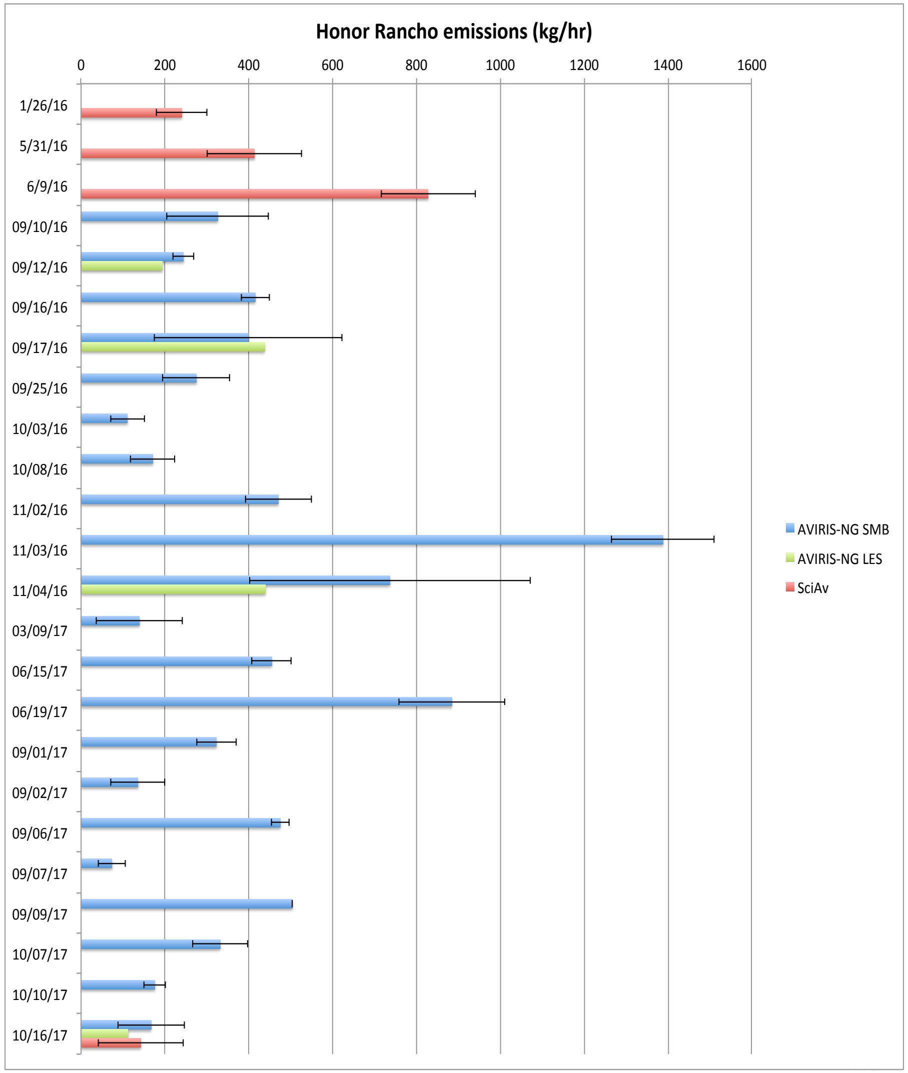


Gas Storage Facility



~30% mean persistence for most sectors

Duren *et al.,* submitted



Thorpe *et al.,* in prep